Turbulence may be key to “fast magnetic reconnection” mystery

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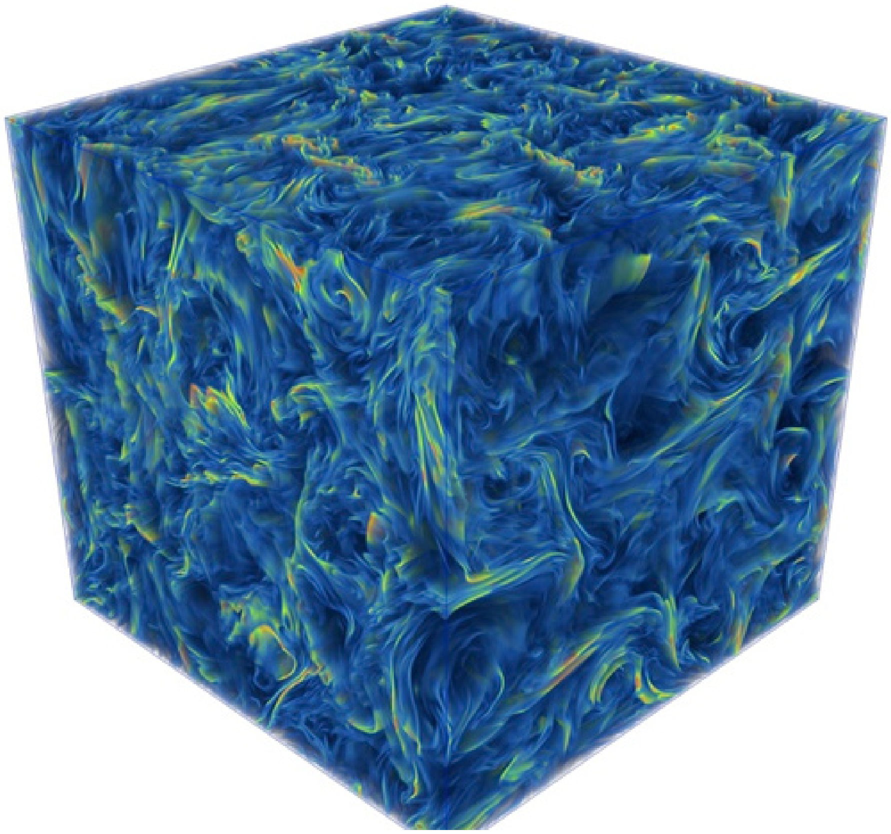

A paper published in the journal *Nature* asserts to have found the key to a long-standing mystery in plasma physics and astrophysics, and it’s all about turbulence. Approximately 70 years ago, Hannes Alfven (Nobel Prize in Physics, 1970) showed that magnetic field lines are “frozen” into a perfectly conducting (or ideal) plasma. This result has been a cornerstone for explaining astrophysical and plasma phenomena. One important implication of Alfven’s Theorem is that magnetic field lines cannot break and change connections. If magnetic field lines are not able to pass through each other more or less freely, they would form a complicated tangle that would strongly impede plasma motion or even thwart it altogether, leading to a “rubber-like” behavior of the plasma. However, the experimentally observed evolution of near-ideal plasmas in most astrophysical situations is essentially fluid-dynamic, where magnetic field lines break and reconnect over fast time scales.

The phenomenon of “fast magnetic reconnection” of the plasmas has puzzled physicists for decades, because it violates Alfven’s Theorem with striking manifestations, such as solar flares and coronal mass ejection. A multidisciplinary team that includes LANL researcher Hussein Aluie of the Computational Physics and Methods group and the Center for Nonlinear Studies reports an alternative explanation, involving turbulence, for the fast magnetic reconnection.

Significance of the research

Fast magnetic reconnection takes place in almost all plasma flows including in star formation and accretion disks, in the solar wind when it interacts with Earth's magnetosphere, and in solar convection – essentially spanning plasma systems at the galactic scales down to those of the Earth. Alfven’s frozen-in result should forbid such fast reconnection from taking place in nature or if it did, it would have to be slow over a million-year time-scale rather than the 15-minute events observed in solar flares. This has been a long-standing puzzle in plasma and astrophysics.

Most efforts to explain the phenomenon of fast magnetic reconnection have relied on microscopic plasma processes to account for the violation of magnetic flux conservation. However, the empirical facts suggest that no microscopic process alone can adequately account for the fast time-scales at which reconnection occurs, which seems to take place independent of the microphysical details.

The new research could lead to better understanding of solar flares and ejections of material from the Sun’s corona. Such powerful space weather could endanger astronauts, disrupt communications satellites, and lead to massive blackouts of electrical power grids.

Research achievements

Some scientists have suspected that turbulence causes the fast magnetic reconnection phenomenon. Therefore, the interdisciplinary multi-institution research team performed magnetohydrodynamic simulations to replicate what happens to charged particles in a plasma within solar flares. The team relied on expertise in astrophysics, applied mathematics, fluid mechanics, data management, and computer science. They adopted a fundamentally new approach to analyze very large datasets similar to that of the Sloan Digital Sky Survey. The scientists conducted a state-of-the-art computer simulation, using novel database methods combined with high-performance computing techniques. They concluded that the motion of the magnetic field lines becomes random and Alfven’s frozen-in theorem breaks down in the presence of the strong nonlinear flow effects often associated with turbulence. The team suggests that nonlinear flow interactions (or turbulence) alone can explain the phenomenon of fast magnetic reconnection.

The research team

Gregory Eyink of Johns Hopkins University led the multidisciplinary team that included Kalin Kanov, Cristian Lalaescu, Charles Meneveau, Randal Burns, and Alexander Szalay, also of Johns Hopkins University; Kai Burger of Technical University of Munich; Ethan Vishniac of University of Saskatchewan; and Aluie.

Laboratory Directed Research and Development (LDRD) through T-CNLS provided partial funding for Aluie’s work while at Los Alamos. The research supports the Lab’s Global Security mission in Space Situational Awareness and the Information, Science, and Technology science pillar using the Lab’s capabilities in numerical modeling, plasma physics, and fluid dynamics.